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AERODYNAMIC ANALYSIS OF A PROFILE FIGHTER TOW TARGET

J. B. Smith

Naval Air Development Center
Warminster, Pennsylvania

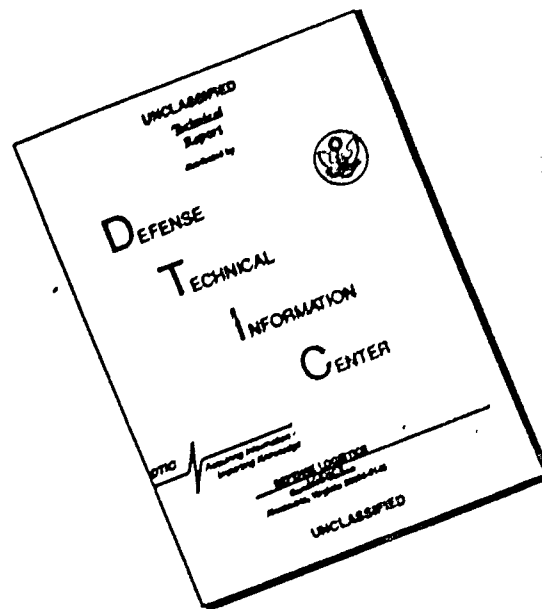22 October 1974

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This report presents the aerodynamic characteristics of a proposed aerial tow target configured to meet the requirements of the Navy Standard Tow Target System for a large gunnery target. The Profile Fighter Tow Target will be both size and performance representative of potential enemy fighter airplanes.

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S U M M A R Y

An analysis was undertaken to determine the aerodynamic characteristics
of a Profile Fighter Tow Target having as a proposed configuration that of
a target which has been produced in limited quantity and flight evaluated by
the Navy. Included in the analysis were derivations of lift curve slope,
pitching moment curve slope (center of pressure), side force, yawing moment,
and rolling moment coefficient variation with sideslip angle, and drag
coefficient. The effect of modifying the proposed configuration to reduce
the drag was also investigated. The results are valid at subsonic Mach
numbers, and provide aerodynamic data which can be used to determine towline
tension and towline egress angle at the target for any subsonic flight
condition.

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LIST OF SYMBOLS

Symbol

A	aspect ratio
b	panel span (measured from target centerline to tip of panel)
C_D	drag coefficient, $\frac{D}{qS}$
C_f	friction coefficient
C_L	lift coefficient, $\frac{L}{qS}$
C_L'	coefficient of force normal to panels, $\frac{L'}{qS}$
C_{L_α}	lift curve slope, $\frac{\partial C_L}{\partial \alpha}$
C_ℓ	rolling moment coefficient, $\frac{\mathcal{L}}{qS\ell}$
C_{ℓ_β}	$\frac{\partial C_\ell}{\partial \beta}$
C_m	pitching moment coefficient, $\frac{M}{qS\ell}$
C_m'	coefficient of moment normal to panels, $\frac{M'}{qS\ell}$
C_{m_α}	pitching moment curve slope, $\frac{\partial C_m}{\partial \alpha}$
C_n	yawing moment coefficient, $\frac{N}{qS\ell}$
C_{n_β}	$\frac{\partial C_n}{\partial \beta}$
C_Y	side force coefficient, $\frac{Y}{qS}$
C_{Y_β}	$\frac{\partial C_Y}{\partial \beta}$
D	drag, positive aft
L	lift, positive up
L'	force normal to panel
$\mathcal{L}$	rolling moment, positive, right wing down
ℓ	target length (equals 30 ft.)
M	pitching moment, positive, nose up; or Mach number
M'	moment normal to panel
N	yawing moment, positive, nose right

LIST OF SYMBOLS (CON'T)

<u>Symbol</u>

q   dynamic pressure

S   reference area (equals 99 ft^2)

S_{wet} wetted area

t/c   thickness to chord ratic

x   distance from target nose; or distance between center of pressure and center of gravity, positive, center of pressure ahead of center of gravity

Y   side force, positive right

y   spanwise distance to panel center of pressure

α angle of attack

α' relative angle of attack normal to panel

β sideslip angle, positive, nose to left of relative wind

Γ wing dihedral angle (equals -30 degrees)

Subscripts

b   base

f   friction

FB   forebody

i   induced

m   miscellaneous

v   vertical panel

w   wing panels

INTRODUCTION

The Profile Fighter Target is included as part of the proposed Navy Standard Tow Target System in order to provide a gunnery target that is both size and performance representative of potential threat vehicles. According to reference (a), a target currently being produced under the trade name "FIGAT" (Fiberglass Aerial Target) can fulfill the requirements for the Profile Fighter Target. The "FIGAT" is 30 feet long, 8 feet high, has a 9 foot wingspan and weighs approximately 500 pounds. It is described in reference (b). A drawing is shown in figure 1.

Under authority of reference (c), an analysis was undertaken to determine the aerodynamic characteristics, including aerodynamic derivatives, centers of pressure, and drag for the Profile Fighter Target, as based on the "FIGAT" configuration. The effect of a modification which would reduce the drag was investigated also.

AERODYNAMIC ANALYSIS

The results of the analysis presented below are applicable at subsonic Mach numbers (up to approximately Mach 0.98). The aerodynamic coefficients are all based on a wing reference area of 99 ft^2 with the target length of 30 feet the reference length for the moment coefficients. The results are summarized in Table I.

The force and moment coefficients normal to the two wing panels, which have a -30 degrees dihedral, and the vertical panel of the target were calculated as follows using slender thin wing theory. For each panel, the normal force coefficient, C_L', is determined from the equation

$$C_L' = \pi \frac{b^2}{S} \alpha'$$

where b is the span of each panel (measured from centerline of target), S is the reference area, and α' is the angle of attack relative to the respective panel (in radians). The moment coefficient corresponding to the moment about the nose normal to each panel, C_m', is determined from the equation

$$C_m' = \frac{4\pi\alpha'}{S\ell} \int_\ell^\ell x \left[b(x) \right] \left[b'(x) \right] dx$$

where ℓ is the target length. The center of pressure of each panel, located as a fraction of the total target length, is obtained by dividing the calculated moment coefficient by the calculated normal force coefficient. That is,

$$\frac{x}{\ell} = \frac{C_m'}{C_L'}$$

Centers of pressure calculated by this method were found to agree with those calculated using charts in reference (d). Because slender thin wing theory assumes an aspect ratio approaching zero, however, normal force coefficients

calculated by this method will be slightly large for a configuration with a finite aspect ratio. In this case the difference is small; nevertheless, the calculated normal force curve slopes ($\partial C_L'/\partial\alpha'$) were reduced by three percent in order to agree with estimates made using the following equation from approximate lifting surface theory at a Mach number of 0.7. (At the Mach numbers of 0.5 and 0.9, there is a variation from this of approximately $\pm 1\frac{1}{2}$ percent, which is considered negligible.)

$$\frac{\partial C_L'}{\partial\alpha'} = \frac{1}{2}\left[\frac{2\pi A}{A\sqrt{1-M^2} + 2\left(\frac{A\sqrt{1-M^2} + 4}{A\sqrt{1-M^2} + 2}\right)}\right]$$

In this equation M is the Mach number and A is the aspect ratio of an equivalent wing with a semispan equal to the panel span and an area equal to twice the panel area. The moment curve slopes ($\partial C_m'/\partial\alpha'$) were recalculated by multiplying the respective adjusted normal force curve slope by the distance to the center of pressure (normalized as a fraction of the target reference length).

Lift due to angle of attack (lift curve slope, C_{L_α}) comes from the vertical component of the force on the two wing panels. Since

$$\alpha' = \alpha \cos \Gamma$$

where α is the angle of attack and Γ is the wing dihedral angle of -30 degrees, and

$$C_L = 2(C_L' \cos \Gamma)$$

(for the two wing panels) where C_L is the lift coefficient, therefore

$$C_L = 2(0.97 \pi \frac{b^2}{S} \alpha) \cos^2 \Gamma$$
$$= 4.57 \frac{b^2}{S} \alpha$$

Then

$$C_{L_\alpha} = 4.57 \frac{b^2}{S}$$
$$= (4.57) \frac{(5.1)^2}{99}$$
$$= 1.20/\text{radian}$$

The center of pressure of the wing panels, which is also the longitudinal center of pressure, was found to be located 18.4 feet aft of the nose. This is 3.5 feet behind the tow point, which is located at F.S. (fuselage station) 179, and 2.75 feet aft of the center of gravity (F.S. 188). The pitching moment curve slope about the center of gravity (C_{m_α}), was calculated as

$$C_{m_\alpha} = C_{L_\alpha} \left(\frac{x}{\bar{c}}\right)$$

$$= 1.20 \left(\frac{-2.75}{30}\right)$$

$$= -0.110/\text{radian}$$

This is a stable moment (increasing nose down pitching moment with increasing angle of attack).

Side force due to sideslip angle (C_{Y_β}) comes from the force on the vertical panel and the sideways component of force on the wing panels. For the vertical panel,

$$(C_{Y_\beta})_v = -\left(\frac{\partial C_L'}{\partial \alpha'}\right)_v$$

$$= -0.97 \, \pi \frac{(5.1)^2}{99}$$

$$= -0.80/\text{radian}$$

For the two wing panels, since

$$\alpha' = \beta \sin \Gamma$$

where β is the sideslip angle,

$$(C_{Y_\beta})_w = -2 \left(\frac{\partial C_L'}{\partial \alpha'}\right) \sin^2 \Gamma$$

$$= -0.40/\text{radian}$$

Added together,

$$C_{Y_\beta} = (C_{Y_\beta})_v + (C_{Y_\beta})_w$$

$$= -0.80 - 0.40$$

$$= -1.20/\text{radian}$$

(Side force is positive to the right.)

The center of pressure of the vertical panel was calculated to be 19.8 feet aft of the nose, and therefore 4.15 feet aft of the center of gravity. The slope of the curve of yawing moment coefficient (about the center of gravity) versus sideslip angle (C_{n_β}) is thus calculated as

$$C_{n_\beta} = \left[C_{Y_\beta} \left(\frac{x}{\bar{c}}\right)\right]_v + \left[C_{Y_\beta} \left(\frac{x}{\bar{c}}\right)\right]_w$$

$$= -0.80 \left(\frac{-4.15}{30}\right) - 0.40 \left(\frac{-2.75}{30}\right)$$

$$= 0.111 + 0.037$$

$$= 0.148/\text{radian}$$

This is also a stable moment (increasing nose right yawing moment with increasing sideslip angle). The net directional center of pressure, with respect to the center of gravity, was calculated as follows:

$$\frac{x}{\ell} = \frac{C_{n_\beta}}{C_{Y_\beta}}$$

$$x = \frac{C_{n_\beta}}{C_{Y_\beta}} \ell$$

$$= \frac{0.148}{-1.20} \ (30)$$

$$= -3.7 \ \text{ft}$$

This is 19.35 feet aft of the nose.

The rolling moment about the target centerline produced by sideslip angle (C_{ℓ_β}) was calculated as

$$C_{\ell_\beta} = (C_{\ell_\beta})_V + (C_{\ell_\beta})_W$$

$$= \left[\left(\frac{\partial C_L{'}}{\partial \alpha{'}}\right) \left(\frac{y}{\ell}\right) \right]_V \ -2 \sin \Gamma \left[\left(\frac{\partial C_L{'}}{\partial \alpha{'}}\right) \left(\frac{y}{\ell}\right) \right]_W$$

where y is the distance to the spanwise center of pressure, measured from the target centerline, for each panel. Since

$$\left(\frac{\partial C_L{'}}{\partial \alpha{'}}\right)_V \approx \left(\frac{\partial C_L{'}}{\partial \alpha{'}}\right)_W$$

and

$$y_V \approx y_W$$

thus

$$C_{\ell_\beta} \approx 0$$

The drag of the target consists of zero-lift drag plus induced drag. However, unless the target is seriously misbalanced, the angle of attack will practically always be so low that the induced drag coefficient, calculated as follows, will be negligible. Using an expression valid for low aspect ratio wings,

$$C_{D_i} \approx \left(\frac{C_L}{\cos \Gamma}\right) \left(\frac{\alpha \cos \Gamma}{2}\right)$$

$$= (1.20 \ \alpha) \left(\frac{\alpha}{2}\right)$$

$$= 0.6 \ \alpha^2 \quad (\alpha \ \text{in radians})$$

Considering only zero-lift drag, then, the total drag of the target is made up of skin friction drag, base drag, and miscellaneous drag from the various proturberances, skids, etc. including any interference drag.

Skin friction drag was calculated according to the method of reference (d), using an equation and charts from that reference. Six different sections of the wing and vertical panels (with different lengths) were considered separately. For each section, the Reynolds number was calculated corresponding to an average flight condition of Mach 0.7 at 20,000 feet. This was compared to the "cutoff" Reynolds number, which is a function of the relative surface roughness height. For an estimated surface roughness height of 0.4×10^{-3} inches (same as ordinary paint), the "cutoff" Reynolds number is just slightly less than the calculated Reynolds number. The friction coefficient for each section is determined as a function of Mach number and Reynolds number, using the lesser of either the calculated Reynolds number or the "cutoff" Reynolds number, the latter of which was used in this case. The resultant total skin friction drag coefficient was calculated as

$$C_{D_f} = \frac{1}{S} \Sigma \left[C_f \left(1 + 2 \frac{t}{c} \right) S_{wet} \right]$$

$$= 0.0104$$

where C_f is the friction coefficient, $\frac{t}{c}$ is the thickness to chord ratio, and S_{wet} is the wetted area of each section. The term $2 \frac{t}{c}$ accounts for the increase in dynamic pressure over the surface due to thickness.

Base drag, arising from the four inch thick blunt trailing edges of the panels, was calculated according to reference (e). The two-dimensional base drag coefficient, based on base area, is determined from the equation

$$C_{D_b} = 0.14 / \sqrt[3]{C_{D_{FB}}}$$

where $C_{D_{FB}}$ is the forebody drag coefficient - that is, drag originating on the surface ahead of the base - also based on base area. This equation was applied to each of the panel sections discussed above and its base. The total base drag coefficient, based on the wing reference area, was found to be

$$C_{D_b} = 0.0132$$

Miscellaneous drag from the various proturberances, skids, etc. was estimated to provide an additional increment in drag coefficient of

$$C_{D_m} = 0.013$$

of which approximately 0.010 comes from the forward skid assembly. The total target drag coefficient is

$$C_D = C_{D_f} + C_{D_b} + C_{D_m}$$

$$= 0.0104 + 0.0132 + 0.013$$

$$= 0.037$$

This value is relatively unaffected by Reynolds number. For example, at a lower Reynolds number corresponding to approximately Mach 0.5 at 40,000 feet (also corresponding to the "cutoff" Reynolds number for a surface roughness height of 1.0×10^{-3} inches), the target drag coefficient would increase by only 0.001.

It can be noted that a significant portion of the total drag is made up of base drag. By tapering the trailing edges of the wing and vertical panels to a point or otherwise reducing of eliminating the blunt bases, this drag could be reduced. As an example, if the final foot of each panel were to be tapered smoothly to a point, a decrease in the target drag coefficient of approximately 0.012 (30%) could be expected. (This would also effect a change in trim angle of attack of about 0.2 degrees, which is not considered significant.)

CONCLUSIONS

An analysis has been made to determine aerodynamic derivatives, centers of pressure, and drag coefficient for a proposed Navy Profile Fighter Tow Target configuration. The results, which are valid at subsonic Mach numbers, show that the target is statically stable, as expected. In addition, they provide the aerodynamic data necessary to determine towline tension and towline egress angle at the target for any subsonic flight condition.

It has also been determined that a significant reduction in target drag (as much as 30 percent) could be accomplished by tapering the trailing edges of the wings and vertical panel so as to eliminate, or at least reduce the size of, the blunt base.

REFERENCES

(a) Carroll, D. W., Proposal for the Development of an Integrated Tow Target System, Naval Air Development Center Report No. NADC-72192-VT, 23 Mar 1973

(b) Maurer, William L., Limited Evaluation of a Fiberglass Aerial Target (FIGAT) and an Electronic Bullet Scoring System, Air Force Flight Test Center, Edwards Air Force Base, Technical Report FTC-TR-71-53, Dec 1971

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(d) USAF Stability and Control DATCOM, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Oct 1960, Revised Feb 1972

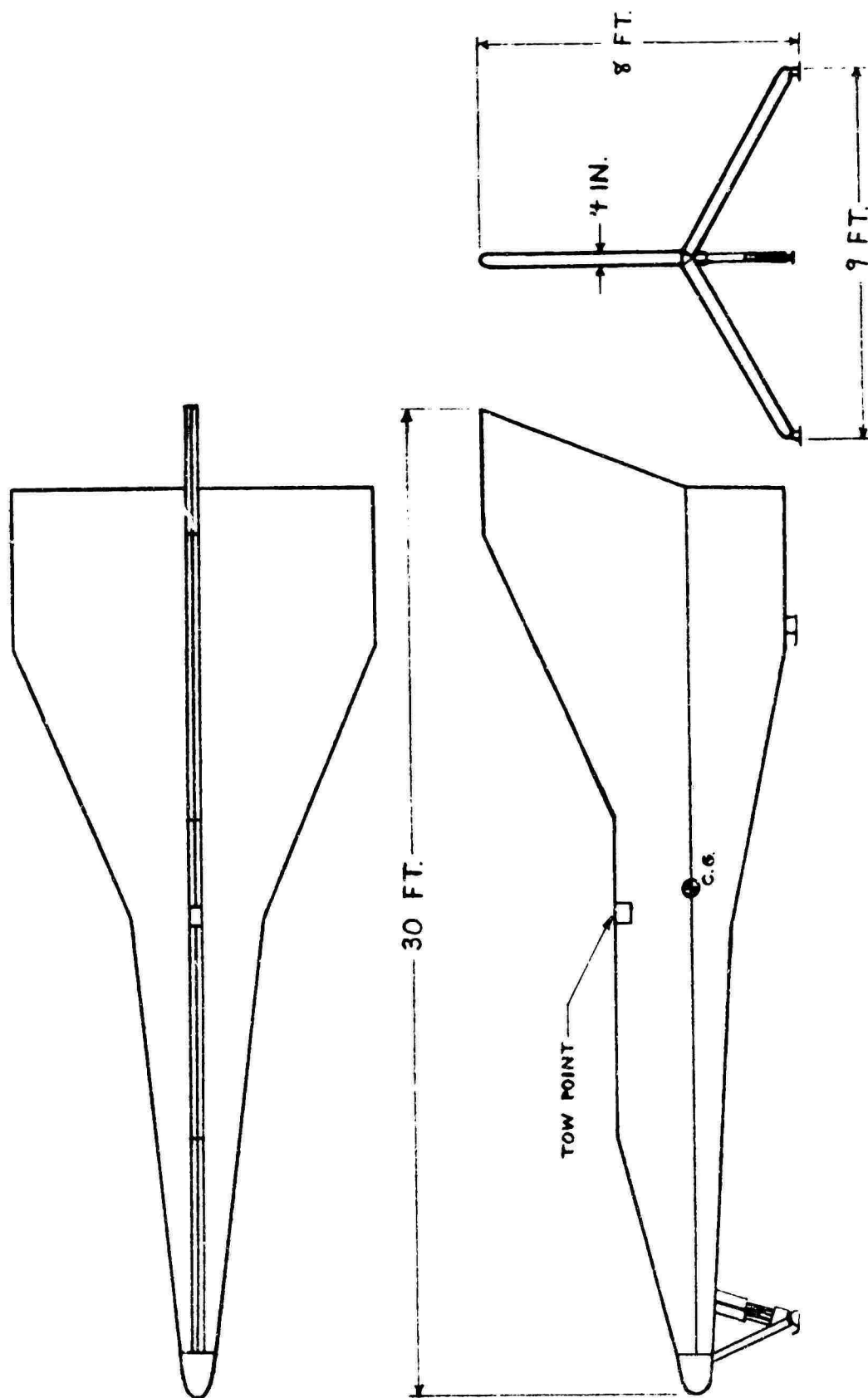(e) Hoerner, Sighard F., Fluid-Dynamic Drag, published by the author, 1958

FIGURE 1 - PROFILE FIGHTER TOW TARGET

TABLE I
SUMMARY OF AERODYNAMIC DERIVATIVES AND COEFFICIENTS
FOR PROFILE FIGHTER TOW TARGET

C_{L_α} :   1.20/rad

C_{m_α} :   -0.110/rad

C_{Y_β} :   -1.20/rad

C_{n_β} :   0.148/rad

C_{ℓ_β} :   ~ 0

C_D :   0.037

Notes:

1. Derivatives and coefficients are defined in text and in list of symbols.
2. All coefficients based on an area of 99 ft^2.
3. Moment coefficients are based on target length of 30 ft; moments are about center of gravity located 15.65 feet back of nose.
4. Surface roughness height assumed as 0.4×10^{-3} inches.